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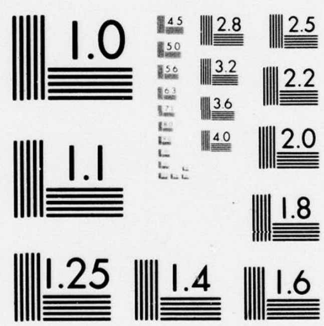

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16. Abstract
Previous studies of binaural hearing suggested that speech sounds are less resistant to masking than are nonspeech sounds; experiments demonstrated that, when the nonspeech sounds are given a message to convey, they act more like speech. Earlier research showed that when subjects are deprived of vision, their walking behavior can be changed by presenting them with binaurally localizable signals, and so tests were run using speech recordings at the exits of the FAA Civil Aeromedical Institute's emergency evacuation simulator. The voices called out, "Exit here," "This way," and "This way out," and people who had the opportunity to listen to them in an evacuation situation in which the illumination level was quite low and the subjects' vision was further obscured as if by smoke or dust performed better than people who did not hear the sounds.

17. Key Words
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ACOUSTIC SIGNALS FOR EMERGENCY EVACUATION

I. Introduction.

In certain kinds of emergencies that require aircraft evacuation, the sense of vision is impaired by the very situation that leads to the evacuation. The problem is increased because evacuation time is related to people's ability to use their eyesight (5). Smoke in the cabin is an example of the sort of problem that interferes with optimal use of lights and otherwise-visible signs to lead people to working exits and to safety. An emergency might also create a different problem in which a perfectly good exit is left unused because it is unattended by an injured crewmember who would normally be nearby to tell passengers which way to go.

Working from the premise that some of the potential difficulties could be removed by the inclusion of an automatically triggered acoustic signal to draw passengers towards functioning exits, the Communication Processes Research Unit of the FAA Civil Aeromedical Institute (CAMI) planned a program of study. The basic concept was of a recorded sound or series of sounds that would be activated when an exit is opened for an emergency. Although one must stop to consider the mechanical and electronics problems associated with being certain that each exit for which sounds are being generated is actually safe for passengers to use, a prior question clearly needs to be considered: Are sounds valuable additions to the other kinds of warnings--primarily visual--that are currently used? If that answer were no, working on the electronics problems would be valueless. To answer the question, the laboratory had to gather information on how best to take advantage of the human auditory system's ability to localize sounds and on how to choose signals that give positive indications of the kind of action that is required without distracting passengers who are already likely to be in an easily distractable and excitable state.

Early evaluation of the literature on the subject suggested several kinds of sounds as candidates for study. Each has apparent advantages and disadvantages that need to be balanced against other. From the standpoint that the best signal is one that communicates the most appropriate information, speech was the obvious choice. Cabin attendants are trained to use their

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The work reported in this report could not have been completed without the contributions of J. D. Garner, W. E. Morris, Earl Folk, J. G. Blethrow, D. L. Lowrey, Judith A. Anderson, Linda Foreman, Debbie Taylor, R. F. Chandler, Lee Forrest, B. G. Nixon, and personnel of the Protection and Survival Laboratory of the Civil Aeromedical Institute.

voices during such emergencies in order to attract the attention of passengers, to bring them rapidly to functional exits, and to hurry them out of the aircraft. Yet speech might not be the best choice of sound for several reasons: It is reported to be more easily masked in binaural listening conditions than is a low-frequency pure tone or narrow band of noise (6,7,11), and the thing that masks speech best is a babble of voices--precisely the most likely masking sound in a downed aircraft. True, the use of speech by cabin attendants is effective, but at the same time that they are shouting at passengers, they are also using other sensory techniques to direct people, and so the contributions of the speech are hard to assess and its necessity is difficult to prove. Speech might not be the best choice if it is too easily masked or too easily misconstrued.

Nonspeech signals, although commonly selected for emergency warnings, are inherently unlikely to convey more than the most rudimentary of intelligence (such as "pay attention" or "be careful") unless the listeners have been taught to recognize the intended special meaning of the sounds. Still, as preliminary studies suggested, a sound pattern of the sort that CHABA recommended (4) for emergency warnings might attract the attention of an untrained listener and might even lead that person to move toward or away from the loudspeaker. Whether a chosen sound might lead some people to move toward itself, some away, and some to freeze in their tracks or to move out of the way (as we have been trained to do when we are driving and hear a siren) was uncertain.

A possible way around this problem would have been to use sounds that move or appear to move in the desired direction. To arrange loudspeakers so that they physically move would be expensive, and the system would necessarily be troublesome to maintain and possibly dangerous, but to arrange speakers and recordings that give the illusion of movement could be fairly easy and safe. Two techniques were considered and tried: Sounds can be made to appear to move from one sound source to another by accurately switching off one source while, in exactly the right way, switching on the next; and sounds can be made to appear to move by the use of stereophonic recordings. Both procedures lead to problems, not the least of which is the need to insure the integrity of electrical connections to the loudspeakers, at least one of which must be at a distance from the signal generators. A crack in a wire would prevent passengers from hearing the intended sound correctly and, in a crashed plane, a cracked wire is not altogether unlikely.

Despite these and related problems, investigations of auditory spatial illusions seemed potentially useful, particularly if such studies might decrease the number of kinds of sounds that could be used for passenger warnings. Thus, the project took on three parts: In one, attempts were made to look at the effectiveness of illusions of movement in calling a listener's attention to a desired part of the environment; in another, experiments were made to help choose effective and efficient signals; in the third, an attempt was made to confirm the value of such sounds in moving people in appropriate directions in a simulated emergency.

II. Sound Location.

Preliminary to formal experiments, several groups of subjects were asked to locate or to find their way to various sound sources. Three kinds of manipulations of auditory space were tried. The first proved impractical and, although the second and third both looked to have possibilities, the ultimate choice of signal led to the selection of the third (and simplest) signal-locating arrangement as the preferred one.

(1) In a circular array of loudspeakers in an anechoic chamber, tonal and noise-band signals were switched from speaker to speaker around the circle. Various switching rates and various on-off ratios were used. Sounds were turned on in each succeeding loudspeaker for various lengths of time before the previous one was switched off in order to increase the apparent smoothness of the transition. Speakers were 30° apart and tests were run with sounds appearing to sweep around the circle over distances ranging from 30° to 180°. Every variation that was tried proved inadequate to the task at hand. Although the illusion of motion was clear during the instant when the sound moved from one loudspeaker to the next, the total effect was a distracting, saltatory sensation rather than a smooth transition of sound from the starting to the ending positions. Listeners recognized that the sound was progressing around the circle, but they reported no inclination to fuse the percept into a single motion to be followed. This result, coupled with the potential problems that any of several broken cables would create in a real emergency, led to the conclusion that switching sounds from place to place is not an acceptable way of calling people to safety.

(2) Motion was suggested by the use of two loudspeakers selected from the circular array and operated as a stereophonic pair. Signals fed to the speakers were designed to give the appearance of a sound that swept at various rates from one loudspeaker to the other over distances ranging from 30° to 180°. The illusion was created by varying signal levels in the two speakers, and it worked well. Listeners reported that the sound progressed smoothly and directly from the starting to the ending positions and that the "pull" of the sound was compelling. Although the stereophonic system shares with the switching system the problem of broken cables disrupting the sound, only two cables are involved (for switched sounds, the number might be far larger), and the strength of the effect might well outweigh at least part of the multiple-wire disadvantage. However, an additional issue needs to be looked at in any discussion of stereophony: the illusion of motion is optimum only for people situated midway between the loudspeakers. For a listener placed much closer to one source than to the other, either between the sources or beyond them, the clarity of the apparent motion is diminished. Partial solutions exist, and formal experimentation would have been undertaken to find the most useful and practical answers, but the question became relatively unimportant in this project: the experiment on choice of signals showed that speech is nearly as resistant to masking as other sounds would be in this kind of situation and that, given its other values, it is the best signal to use, so the development of tones or noise

bands that show people where to move to was unnecessary. Had nonspeech signals clearly been the best choice, a stereophonic tonal sweep would surely have been the signal used.

(3) Only one loudspeaker at a time was used and subjects were asked to locate which one it was. For listeners whose head movements were restricted by a simple head-positioning device, front-rear errors were fairly common, as was expected (a little head movement may still have been available because listeners invariably were able to judge front from rear correctly better than 50 percent of the time). When free head movement was permitted, such errors decreased nearly to zero, and the sounds were easy to localize accurately. When speech was selected as the evacuation-warning sound, the sound itself could contain the message to move, and the previously appealing means of creating an illusion of movement were no longer necessary. A fixed source would be localizable, and spoken phrases would not move away and be lost during a stereophonic sweep to another loudspeaker. Logic, then, in conjunction with specific experimentation, led to the choice of a one-channel, single transducer reproduction system for use in simulated evacuations.

III. Choice of Signal.

The most important findings in this project are those related to masking. In normal situations, unheard or unclear messages are useless; in emergencies, they are dangerous. Intelligence-carrying sounds thus must be loud enough to be heard over background noises. They must also be quiet enough not to interfere with other messages. An appropriate warning signal to place at an emergency exit in a smoke-filled plane must therefore be resistant to masking sounds that will, from time to time, rise in level enough to interfere with the hearing of people who need to be aware of the warning. Additional requirements for a warning sound in this kind of situation are that it be easily localized (so that a listener can tell which way to move to get to the source) and that it clearly identify itself as a warning and as something to be reached. A measure of the resistance of a sound to noise is the masked threshold; a measure of the ability of the binaural auditory system to deal with a given masked sound is the "masking-level difference" (MLD), a number that compares the monaural masking of a signal (or the special kind of binaural masking that occurs when both ears receive identical signals and identical noises, which is exactly the same as monaural masking) with one or another kind of binaural masking. Usually the kind of binaural masking used is the one that gives the best improvement; that best one is easy to produce in the laboratory simply by inverting the phase at one earphone either for the signal or for the noise (but not for both signal <u>and</u> noise); in the real world, this "antiphasic" listening condition cannot be replicated, but a close analog arises when the signal and the noise come from well-separated places (which is what we would normally find during an emergency evacuation in which the signal we are interested in is produced at a spot above an exit). When one is concerned with <u>message</u> reception rather than with a simple threshold of hearing, a similar kind of binaural measurement is made, but in this

"intelligibility-level difference" (ILD) procedure, one does not compare masked thresholds during monaural and binaural hearing, but rather the understandability of masked words at some predetermined level of accuracy (usually either 50 percent better than chance for a limited vocabulary from a closed set of words or else simply 50 percent correct) during monaural and binaural listening. ILDs show considerably less binaural-listening advantage than do MLDs, and a common (though unsubstantiated) explanation is that speech signals require a more complex kind of analysis than do nonspeech signals. An alternative explanation is that the ILD is measured well above the masked threshold and therefore involves either a different kind of processing or attention to a different aspect of the signal. Neither explanation is well tested, though, and this lack of pertinent data meant that we could not draw any useful conclusion regarding the resistance of speech to masking, especially for the application needed in this project.

The ILD studies (in which speech is the signal) show a binaural advantage of only about 5 dB, but the MLD studies show an advantage of 15 or even 20 dB for some low-frequency tones and noises (6,11,12). Levitt and Rabiner (7) speculated that the smaller binaural advantage for speech results from the need to attend to higher frequency components of the signal; high frequencies produce smaller MLDs than do low frequencies.

A. Procedure.

Comparisons of MLDs with ILDs always seem to lead to complex and untestable proposals about the mechanisms of neural and perceptual analysis. In order to try to avoid some of those problems (and to avoid the temptation to add another untestable speculation to the list), we devised a measurement that is analogous to the ILD but that doesn't require the use of speech signals. The sounds chosen were the hierarchical series of six computer-generated signals that have been used for several years by Charles I. Berlin and his colleagues at the Louisiana State University in their many studies of hemispherical dominance for speech perception.

The sounds (in order from nonspeech through speech-like to speech) are a 750-Hz tone burst, a shaped noise burst, a tone sweep with 125 Hz as the lowest frequency, the second formant of the syllable /ga/ (called a "bleat" in the literature), the vowel /a/, and the complete syllable /ga/. The generating program is designed to give all the sounds similar temporal patterns, and all but the tone burst and noise burst have similar shifts in fundamental frequency. None of the sounds has any inherent semantic value, and the kinds of presentations used in this study permitted no contextual significance either. If identifying these six nonwords is a task similar to identifying words--that is, if a "discrimination-level difference" (DLD) for these sounds is similar in size to an ILD--then the reason for less binaural advantage in an intelligibility test than in a threshold test might be related to the meaningfulness of the signal (but it might also be attributed to the level-above-threshold). And, of course, if the DLD is similar in size to an MLD, then level-above-threshold could clearly be dropped as a

reasonable explanation since DLDs are measured at suprathreshold levels and MLDs are not.

Twelve young adult subjects were used for these tests. Anyone with an audiometric threshold greater than 20 dB hearing level from 100-6,000 Hz was rejected as was anyone with binaural asymmetry greater than 15 dB in that same frequency range.

A training program was included in the experiment; listeners were expected to reach a high level of proficiency in recognizing the six sounds immediately and accurately. A half-hour training period was enough to make the sounds so familiar that any uncertainty a subject felt about an identification would be based on the masking condition and not on the ability or inability to remember which sound was which. The idea is parallel to the use of known words in a valid intelligibility test: hesitations and errors in identification ought to result from the experimental condition and not from a vocabulary problem. Since subjects were able to name the six sounds (they were trained to assign the numbers 1 through 6 to them) with high accuracy within 2 or 3 minutes, the 30-min session produced overtrained listeners, which was just what was required.

A total of 2,400 judgments was made by each subject. Half of the presentations were used to measure MLDs and half were used to measure DLDs; half of the subjects were tested on MLDs first and half on DLDs first. Each of these halves was further halved into a "homophasic" (NOSO--that is, both noise and signal are in phase at the two earphones) and an "antiphasic" (NOSπ--that is, noise is in and signal is 180° out of phase at the two earphones)portion.

In the measurement of MLDs (which half of the subjects did first), a broadband white noise was fixed at an overall sound-pressure level (SPL) of 81 dB; only the six signals had their levels manipulated. Groups of 30 sounds (five samples of each of six signals) were presented at one of 20 signal levels; the order of levels was random. The 20 attenuation steps were 1.5 dB apart, so a range of 28.5 dB was covered. Subjects were asked to say the word "yes" whenever they thought they heard a sound above the background noise; an observer outside the sound-treated testing booth, who could hear the sounds without the masking noise, recorded a detection for that item if a response was received during the first 2 seconds of the 6-s intersignal interval. An occasional empty interval was included to sample criterion effects: although listeners were instructed to respond "whenever you hear a sound," they apparently set fairly strict criteria for themselves, and the false-alarm rate for this part of the study averaged about 9 percent.

In the measurement of DLDs, the noise was fixed at the same overall level--81 dB SPL--as for the MLDs and the signals were similarly presented. However, instead of being asked for detection of sounds, subjects were asked to identify which of the six sounds they heard, and the observer recorded their responses. The false-alarm rate was predictably low since the signals were generally somewhat above threshold: for this part of the study, the rate was only about 5 percent. Errors among the six signals were also analyzed.

A matrix was prepared to show which sounds were mistaken for which. Again, the number of errors indicated that listeners set themselves strict criteria: only 4.5 percent of all responses were errors, and the numbers were so small as to prevent any useful interpretation of the kinds of interactions that misled subjects.

The possible outcomes of the MLD tests would be one in which MLDs for all six signals would be similar to each other, one in which the MLDs would increase in size from the most to the least speech-like sounds, an unlikely one in which the MLDs would decrease from the most to the least speech-like sounds, and one in which they would vary randomly from sound to sound. Similar outcomes would exist for the DLD tests. Each combination of results could be interpreted as evidence for a particular type of perceptual analysis and could help to answer questions about whether the differences in size between MLDs and ILDs come about because of the relative levels above the masking noise at which judgments are made, because of a differential treatment for speech signals, or because any meaningful signal--speech or not--is "earmarked" for special treatment. This last idea is particularly interesting because it could indicate that one kind of sound becomes like another when both have had a degree of meaningfulness imposed upon them, and if that were true or nearly true, the selection of the kind of sound to use as an emergency warning signal would be simplified.

B. Results and Discussion.

In order to compare the various psychometric detection and discrimination functions, a repeatable method was needed to locate the 50-percent-correct points. Probit analysis (3) was used not only because it provides a consistent approach to finding specific values within cumulative distributions, but also because it permits comparisons of the slopes of the curves. If curves that plot the percent correct detection as a function of signal level differ in slope (which can be interpreted as inversely related to judgmental difficulty) from curves that plot correct discrimination, the fact is not apparent in these data: the slopes of the linear parts of the detection curves is 12-17 percent per decibel and on the discrimination curves it is about 9½-16 percent per decibel.

One way to look at the data is illustrated in Figure 1. It shows an abscissa laid out according to the predicted hierarchy of the sounds (running from those that are clearly not related to speech on the left to those that are clearly speech sounds on the right). The ordinate is the MLD for the detection task and the DLD for the discrimination task; that is, it is the difference in decibels between 50 percent performance in the N0S0 condition and 50 percent performance in the N0Sπ condition. Each sound shows a similarity between its threshold and its above-threshold score, which suggests that the often-reported difference between MLDs and ILDs may not easily be attributed to the difference in level-above-masked-threshold at which they are measured. Obviously, a careful study specifically treating that question needs to be done before the theoretical issue can be dealt with

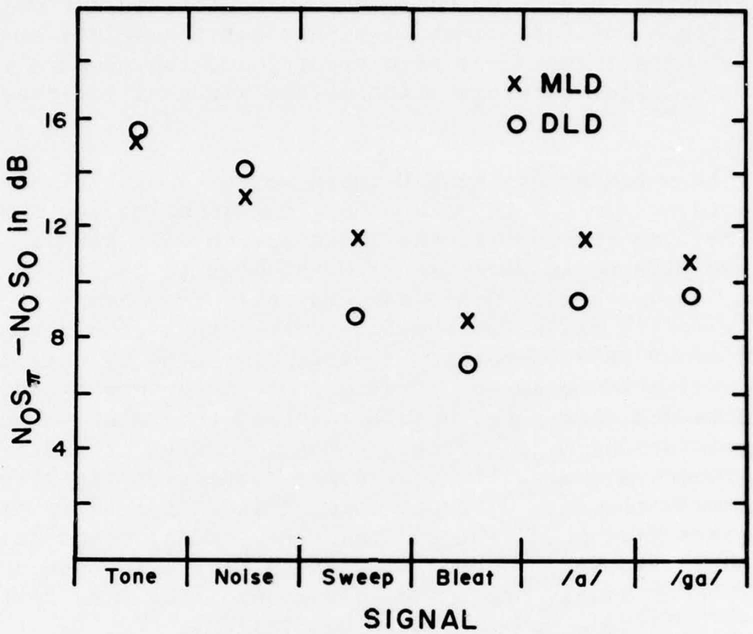

Figure 1. Comparisons of masking-level differences and related discrimination-level differences.

in detail, but the implication is clear in this figure. Statistically too (see Table 1), the MLD and DLD scores are not significantly different.

No simple statistical test was available to permit a judgment of the differences between pairs of sounds, but an inference can be drawn from the fact that the deletion of the tone-burst data from the analysis (Table 2) decreases the significance level of the F-test that shows the sounds to differ from each other. However, even without the tone burst, the sounds proved different at the 1-percent level. Figure 1 suggests that the noise burst and the bleat may be the major contributors to that difference, and logic suggests that the bleat is less likely to represent a true change toward a lower (speech-like) score than the noise is to represent a true change toward a higher score. The noise is the most likely reason, then, for the significant difference among the sounds.

Thus it looks as if the four pitch-varying sounds form a related group that might properly be called "speech-like" even though only two of them--a vowel and a nonsense syllable--are heard as if they might have been produced by a human vocal system. The DLDs for these sounds are still larger than are the previously reported ILDs for true words. In order to permit accurate comparisons to be made, 12 subjects were used to collect MLD and ILD data on spondaic words. The results are almost identical to those reported for spondees by Tobias and Curtis in 1959 (11) and are similar to those reported

TABLE 1. Masking-Level Differences and Discrimination-Level Differences for the Six Test Signals and Results of the Statistical Analysis of the Data

DATA	Threshold $N_0S_0-N_0S_\pi$	Discrimination $N_0S_0-N_0S_\pi$
0 tone	15.04	15.23
1 noise	13.29	14.17
2 sweep	11.72	8.90
3 bleat	8.67	7.29
4 /a/	11.86	9.65
5 /ga/	10.83	9.79

Analysis of Variance	SS	df	MS	F	
A Thresh-Dis.	3.39	1	3.39	3.46	$p>.10$
B Sounds	67.73	5	13.55	13.83**	$p<.01$
AB Residual	4.91	5	.98		
TOTAL	76.04	11			

for consonant-nucleus-consonant (CNC) words by Levitt and Rabiner in 1967 (7) (a nucleus in this sense is a vowel, diphthong, or vowel-like sound). Figure 2 combines the data from Figure 1 with the values for the CNCs and the spondees. Here the data are presented in a form that helps to show the way in which DLDs result from the position the material falls at on a continuum that runs from meaningless to meaningful. Simple, low-context or low-semanticity sounds have their MLDs and DLDs at about the same level as each other, and the tone burst and noise burst, which fit this description, are shown in the left third of the figure. Complex sounds with relatively low meaningfulness form the center category in which the MLDs and DLDs seem to be separating. An interpretation is that these acoustically varying signals contain somewhat more semantic information than the simplest sounds--especially after we impose some meaning on the sounds (for instance, by requiring subjects to learn to discriminate between them, to make an intellectual judgment based upon them, or perhaps to recognize that they are providing emergency information). Finally, real words--semantically rich language units--form the category shown on the right. Here, the MLDs and DLDs (or ILDs) are further separated. Note, though, that the separation is large only for the Levitt and Rabiner CNCs. For spondaic words, the separation is scarcely more than it is for speech-like sounds. Assuming that the CNC measurements are unusual (and indeed the MLD shown is higher than those seen in other studies that include presumably comparable measurements), then a conclusion that speech and information-bearing nonspeech are similarly susceptible to masking is warranted. This statement might be

TABLE 2. Masking-Level Differences and Discrimination-Level Differences for All Signals Except the Tone and Results of the Statistical Analysis of the Data. For Informational Purposes This Analysis Also Includes an Analysis of the Obvious Difference Between NOSO and NOSπ Conditions.

Analysis of Variance

DATA	Threshold NOSO	Threshold NOSπ	Discrimination NOSO	Discrimination NOSπ
noise	33.14	19.85	31.58	17.41
sweep	28.74	17.02	27.98	19.08
bleat	29.22	20.55	27.75	20.46
/a/	27.44	15.58	26.46	16.81
/ga/	28.11	17.28	28.46	18.67

SOURCE	SS	df	MS	F	
A (Thr vs Dis)	0.26	1	0.26	<1	
B (NOSO vs NOSπ)	563.60	1	563.60	1105.09***	p<.001
C (Sounds)	35.51	4	8.88	17.41**	p<.01
AB	2.14	1	2.14	4.20	p>.10
AC	5.52	4	1.38	2.71	p>.25
BC	16.86	4	4.22	8.27*	p<.05
ABC = residual	2.03	4	0.51		
TOTAL	625.92	19			

challenged because the tone burst and noise burst are so much higher than the other sounds. Still, those two sounds have two other important characteristics that distinguish them: (i) they are nonvarying signals, and (ii) they are discriminated in this experiment just as soon as they are audible (their MLDs and DLDs are practically identical). Both points suggest that they are unlike the sorts of sounds that would be usable as emergency signals.

As a result, since the kinds of nonspeech sounds that might be chosen to attract passengers to emergency exits behave similarly to speech sounds, and since speech has the advantage that it can carry clear and unequivocal messages, speech must be the optimum kind of signal to use. Similar conclusions based on philosophical arguments alone have been made with regard to the delivery of messages to the deaf (9) and to the selection of general-purpose warnings (2).

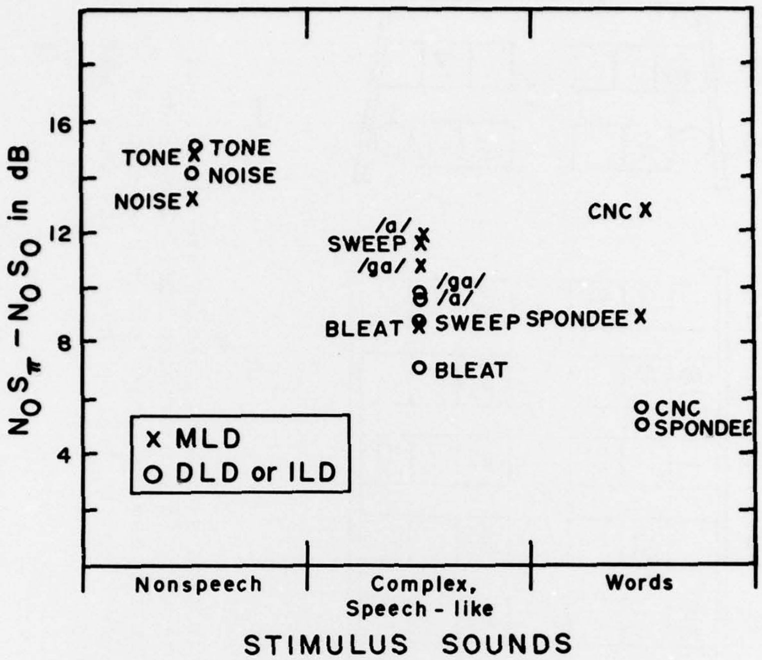

Figure 2. The data from Figure 1 combined with related data on masking-level differences and intelligibility-level differences for words.

IV. Simulated Emergency Evacuation.

A. Procedure.

Studies of how people hear sounds in the laboratory may be instructive enough to tell us all we need to know about what they will be able to hear in a real emergency, but it might also be useful to try to confirm these findings in a simulation. Since CAMI uses an evacuation simulator for investigating the patterns of movement and the durations required to clear a cabin of subjects, a program was developed in which the simulator was used in conjunction with a standard test series run by CAMI's Protection and Survival Laboratory.

The test facility has been described in detail elsewhere (1). Some modifications of the simulator have been made since that report was written.

The device is a C-124 fuselage section, approximately 12 ft wide and 77 ft long, mounted on a hydraulically movable platform. For these tests the platform was kept flat and left in its lowest position, which places the exit thresholds about a foot above ground level. From those thresholds down to

EVACUATION SIMULATOR

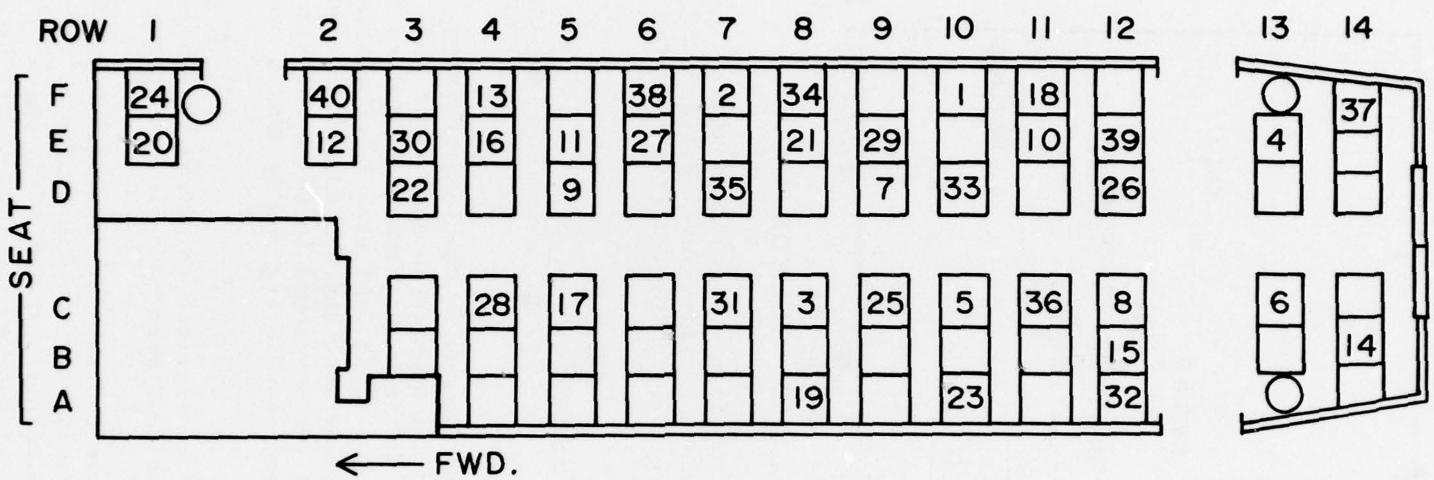

Figure 3. Schematic representation of the CAMI evacuation simulator. Exits are shown, and the positions of the three timekeeper/observers (one near each exit) are shown by the circles. Seats are labeled to show the row and seat-letter designation except for those seats that were occupied during the tests; those seats show the vest number of the person using that seat.

ground level, 8-ft wooden ramps were fitted so that when subjects had cleared a doorway, they would not have a long step down. The ramps were enclosed in 8-ft-wide, light-trapped tunnels designed to minimize the subjects' use of visual cues. An observer stationed in each tunnel guarded against falls and other possible safety problems.

The interior of the simulator is illustrated schematically in Figure 3. Most of the rows consist of two three-abreast seats separated by a 15-in-wide aisle. Two exit doors are in the right wall of the simulator, one toward the front and one toward the rear. Opposite the right rear door is a left rear door. The three exits are approximately the same size and are at least 42 inches wide and 72 inches high. In addition to these "emergency" exits, the simulator has a set of double doors in the rear bulkhead through which subjects were led into the cabin before each test run. Near this entrance, a worktable held three Advent model 202 cassette players and a Kudelski Nagra II tape recorder, all under the supervision of an electronics technician. Each cassette player was used to feed sounds to one of three 8-in loudspeakers, one above each of the three exits. The microphone for the tape recorder was placed out of the way, in an overhead position near the middle of the cabin, to pick up any sounds that might have proven important in the evacuation tests; no unusual sounds appeared, and these recordings proved to be unimportant except to give an estimate of the ambient noise level.

Two 16-mm motion-picture cameras were also placed overhead, one focused on the front exit, the other focused on the two rear exits. Between them the cameras permitted observations of most of the seats in the cabin. Because of the low illumination level used in these tests, the cameras were fitted with light amplifiers: a Javelin Night Viewing Device model 221 was used with each camera; these battery-operated systems are capable of 47 dB of amplification.

During the period in which subjects were being seated and being given instructions, a bright level of cabin illumination was used. However, at the instant that the people were told to leave the cabin, the light level was dropped to the minimum emergency level permitted by Federal Aviation Administration rules. In addition, subjects were fitted with goggles that had an inhomogeneous neutral-grey coating that imitated the effects of smoke in the cabin while permitting observers and cameras adequate light to perform their tasks. The already low level of illumination was decreased by about 50 percent by the goggles, which also created hazy, distorted images, and generally obscured vision; no subject could use his or her vision well.

In each of the two studies, 40 subjects were used. They were selected to represent a range of ages--men, women, and children were included. None of the subjects had participated in an evacuation test before. Table 3 shows the age and sex of the person in each seat of the simulator during each of the two studies. Note that the same randomly selected seats were used for both groups and that an attempt was made to match the age and sex of the two

TABLE 3. Age and Sex Matches for the Two Test Groups
Organized According to Assigned Seat Number

Seat No.	1st Group Age & Sex	2nd Group Age & Sex
1E	36F	59F
1F	25F	24F
2E	27M	25M
2F	29M	30M
3D	27F	23F
3E	23M	21M
4C	23M	23M
4E	17F	13F
4F	22F	20F
5C	15M	18M
5D	60M	43F
5E	23M	15M
6E	22M	21M
6F	19F	20F
7C	36M	57M
7D	24M	23M
7F	27M	27M
8A	13F	13M
8C	34F	49F
8E	29F	26F
8F	24M	24M
9C	22M	22M
9D	14M	16M
9E	30F	25F
10A	27M	24M
10C	23M	22M
10D	20M	19M
10F	24F	22F
11C	28M	28M
11E	21M	20M
11F	34M	46M
12A	26M	24M
12B	49M	30F
12C	18F	17F
12D	58M	32F
12E	33M	33M
13C	15M	17M
13E	35F	55F
14B	28F	25F
14F	25M	23M

subjects assigned to each seat. A few mismatches were unavoidable but their influence on the results is believed to be negligible.

During each of the two studies, the first three evacuation exercises were devoted to the investigation of the influence of sound on subjects' speed in leaving the cabin. (Since the work done by the Protection and Survival Laboratory commonly requires experienced subjects and since experience would have modified the performance of subjects for the acoustic-signal trials in ways that would minimize any potentially measurable effects, the two sets of data could be collected together. The early runs, when subjects were still naive about the nature of the test space and of the test, could be used to advantage for the work reported there; those same runs served to help train the subjects for the portions of the work done for the Protection and Survival Laboratory.) The first run for the first group included recorded sounds presented from the loudspeakers above the doors. The second run for that group used no special sound. The third run used the sounds again. For the second group, the first run was without the recorded sounds, and the second run was with them. The third run was the same for both groups so that performance at that point could be compared.

Whenever sounds were presented, they were presented in the same way. A different talker was heard at each exit; at the right front exit, a woman with a soprano pitch range spoke; at the left rear exit, a woman with an alto pitch range spoke; and at the right rear exit, a man with a tenor pitch range was the talker. These three were randomly selected from a collection of eight talkers, four women and four men, each recorded saying the phrases, "This way out," "This way," and "Exit here." The phrases were spoken calmly at a constant level and were repeated in no particular order, continuously with minimum pauses between phrases. Through the courtesy of American Airlines, we had been able to measure the ambient sound level during several fairly noisy evacuation simulations run as training exercises at their facility in Fort Worth, Texas. Their average sound-pressure level of 67-68 dB seemed likely to be the maximum we would encounter in our tests, and so signal levels were adjusted to be easily audible above that much background noise yet not to be loud enough to frighten passengers or to interfere with their hearing of instructions that might be shouted by cabin attendants in a real emergency. The level selected was approximately 75 dB SPL 3 ft from the loudspeaker cone. This value is not set according to FAA report number FAA-RD-76-222, "Aircraft Alerting Systems Criteria Study," a contracted work done by the Boeing Commercial Airplane Company's Systems Technology--Crew Systems organization. Although the report is generally well researched and accurate, in this one instance, its recommendation, when followed back to the original source, is based on conjecture rather than on data. Had more tests been practical, it would have been good to measure whatever changes might have occurred if the signal level had been increased by 10 dB and by 20 dB. As it was, though, only one level was used, and the signal was audible throughout the cabin but was not obtrusive. The ambient sound level during these tests was somewhat lower than that measured in the noisy American Airlines tests; the sound generated at our microphone was 62-67 dB SPL, and even assuming that

some sounds would be more intense at a subject's head (a foot below the microphone), it was certainly not enough to interfere with anyone's clear hearing of the voices.

A staff member was placed beside each of the three exits at a station far enough out of the way to prevent subjects from running into the observer. (Observer positions are shown in Figure 3 as circles.) Because the observers were also safety monitors, they could leave their posts rapidly if necessary; no problems arose. Each observer timed each evacuation in order to confirm the data that were planned to be provided later by an analysis of the motion-picture film. The time recorded represented the duration between the moment that the evacuation was started and the moment that the last person using the exit crossed the threshold.

Between the second and third runs on each group, the subjects were brought back to their seats but were permitted to stay for a few minutes without their goggles while they filled out a questionnaire about their experiences during the first two runs. A copy of the questions with a summary of the answers is seen in Figure 4. The questionnaire had two objects: one was to collect a bit of information about the subjects' impressions of the experiences they had had; the other was to keep the people motivated to continue, both by providing them with a new kind of task and by giving them some sense of intellectual participation in the experiment.

Each group's participants were gathered together in the lobby of the CAMI building first thing on the morning of that group's tests. Each person was assigned a tie-on vest with a large number displayed on the front and back; the numbers were used to help analyze the film. For the first group, the vests were assigned randomly and the participants were later seated in the simulator in a previously determined random order according to vest number (see Figure 3). For the second group, the same vest numbers were assigned to the same seats, but the vests were not handed out randomly. Rather, they were distributed in a way that attempted to match the second-group person's age and sex to the age and sex of the person who was assigned that number in the first group.

After vests were distributed and release forms were signed, a member of the Protection and Survival Laboratory staff gave a briefing according to this script:

"We appreciate your participation in our program. You will be helping us determine the best means to improve chances of escape and survival from emergencies on commercial airlines. Portions of the test design may seem unrelated to what you might expect if you were aboard a crashed aircraft. However, at this time, accept the fact that these are small pieces of an overall search for better passenger guidance. Following each test group, I will pass on information we gained so you can better appreciate what we are after. The slightest clue in advance can possibly alter your performance.

QUESTIONNAIRE VEST NUMBER_________ DATE_________

NAME____ AGE______ SEX____

This questionnaire relates to your experience and observations during the two evacuation tests just completed.

1. Before the first test started, I: a) did 34/32 b) did not 6/8 notice where my seat was in relation to the exits.

2. During the first evacuation, I was: a) frightened 4/2 b) moderately concerned 21/22 c) indifferent 15/16.

3. I used the same exit during both evacuations: YES 38/34 NO 2/6. If NO, explain why you changed: less crowded (1/3); closer (1/1); curiosity (0/2).

*4. I chose the particular exit I escaped through because: a) it was nearest 30/26 b) I didn't see any others 1/2 c) I followed the person ahead of me 7/14 d) I heard something that led me to it 3/2 e) other (please explain) 1/4 thought only exit was forward (1/0); less crowded (0/2); saw light (0/1); saw sign (0/1).

*5. I was able to get out of the airplane by: a) feeling my way out 18/12 b) following the person ahead of me 13/15 c) remembering the instructions 5/7 d) seeing the exit 12/14 e) other (please explain) 0/2 instinct (0/1); knew exit location (0/1).

6. Did you trip, stumble, or fall during the evacuations? YES 7/5 NO 33/35. If YES, explain how or why: don't know (2/0); bumped into seat (2/1); "others' movement" (1/0); stumbled off ramp after exiting (0/2); tripped on carpet (1/0); ran into something (0/1).

7. Were you delayed by the person in front of you? YES 17/14 NO 23/26 If YES, explain what happened: person stopped (1/0); stumbled (2/0); slow getting into aisle (1/2); everyone up at once (1/0); don't know (1/0); slow moving (4/5); person in front stumbled or dropped something (1/0); ran into someone (1/1); could get out faster alone (1/0); couldn't see (1/0); felt for person (0/1); confused (0/1); natural delay (0/1).

8. Did you find the evacuations to be a) very difficult 0/0 b) difficult 3/0 c) neither difficult nor easy 16/15 d) easy 16/16 e) very easy 5/9.

9. Was there any time during these two evacuations when you felt panic? YES 7/2 NO 33/38 If YES, explain: when lights went out (2/1); when told to get out (3/0); "shining lights on the ramp" (1/0); thought people would stampede (1/0); didn't know where to go (0/1); when bell sounded (1/0).

10. Did one particular thing help you to escape from the airplane more than anything else? YES 16/17 NO 24/23 If YES, explain: knew exit location (4/7); saw exit (2/2); followed someone (2/1); light(s) (2/0); calmness (2/0); was close to exit (5/3); felt my way (0/2); exit signs (0/2); voices (1/4); knew it was a test (0/1).

COMMENTS: Plant someone who will panic; panic is missing; I never panic; too little light; in a real emergency many would trip and fall and be unaware of exit locations; easier than expected; instructions unclear; intercom unclear.

*Number of responses may add to more than 40 on this question.

Figure 4. Questionnaire, including summaries of the responses received. The figure to the left in each pair is the number of people (out of 40) in the first group who responded to that part of the item; the figure to the right in each pair is the number of people (out of 40) in the second group.

You are asked to leave the aircraft in each test according to the information presented at that time.

"There are eight tests scheduled and they should not involve more than 3 hours. Breaks will be scheduled between test groups, so you can relax and ask questions if you like. For laboratory studies such as these, times for you to leave the aircraft are the means we use to quantitatively choose best methods to aid passengers out of aircraft. Once we move out to the aircraft, I will brief you further on the setup. We are going to ask that you wear a pair of semi-opaque goggles which will simulate visual obscuration you could encounter in a crash. Directions on how and when to don goggles will be given in the aircraft. With the help of your imagination, you will feel that you are essentially in a cabin with a certain amount of obscuration by smoke or dust. We will not be using escape slides today; we'll just be getting out of an aircraft that is sitting 1 ft off the ground with ramps to the ground."

Once subjects were briefed, they were taken to the simulator and seated. Goggles were distributed and instructions were given about how to adjust them and how to be sure that the straps remained higher than the ears. A visual inspection was then made by a staff member. A final briefing in the aircraft repeated the pertinent matters touched on in the lobby briefing and added several other points. Subjects were told that the lights would go out and that only emergency lighting would remain on during the period in which they were to leave the aircraft; a demonstration of the lighting change was given. A safety briefing was given to point out potentially hazardous parts of the simulator cabin and to warn against trampling on anyone who might have tripped and fallen, against stumbling on the ramp, and so on. The people were reminded to leave their goggles on throughout the evacuation and to remove them only after reaching the outside. A demonstration was given of the starting signal (a loud, continuously ringing, electric bell that was turned on for 10 s immediately prior to the start; the actual starting signal was the cessation of the bell). Subjects were told that seatbelts would not be used. Finally, they were told that if a problem came up, the bell would be turned back on and that they should freeze in place. No emergency arose. Just before each run, subjects were told to get ready and to fit their goggles. Then the bell was turned on and after 10 s, it was turned off; simultaneously, the lights were turned down, the test director shouted, "Get out," and the three timers started their stopwatches. During appropriate trials, the cassette recordings that fed the loudspeakers were started at that same instant. During the ready period, either immediately before or during the time when the bell was ringing, the tape recorder and the cameras were started.

B. Results and Discussion.

Table 4 (A) shows the total time recorded by the timekeepers for the first groups. A full tabulation of the frame-by-frame motion-picture film analysis for the first group is shown in Table 5. Some of the vest numbers shown are considered inaccurate by one or more of the staff observers, but the

TABLE 4. Timekeepers' Results. Total Time From Start to Last Person's Crossing the Threshold of That Exit is Shown for the Three Runs for Each Group

A - First Group

Exit	Time in Seconds 1st run (Sound)	2nd run (Silent)	3rd run (Sound)
Right front	28.0	24.4	19.8
Left rear	26.0	22.8	22.8
Right rear	26.0	22.8	22.6

B - Second Group

Exit	Time in Seconds 1st run (Silent)	2nd run (Sound)	3rd run (Sound)
Right front	44.0	34.2	26.8
Left rear	12.0 (approx.)	22.8	22.8
Right rear	28.2	25.1	22.8 (approx.)

general pattern of evacuation is clear. In this group's runs, the first and third were with the acoustic signals turned on and the second was without.

Table 4 (B) shows the total time recorded by the timekeepers for the second group. During the second group's runs, both of the Night Viewing Devices failed and so no film was available for analysis. Thus, the numbers in this table provide the only data for comparison with the first group. Of course, some additional information was available from debriefings of the staff observers and from comments made by subjects. In this group's runs, the first was without the acoustic signals turned on and the second and third were with.

An immediately apparent difference between the groups is the way in which they selected exits. In the first group's first run (with the speech recordings being played), 18 people used the front exit, 10 used the left rear, and 12 used the right rear. This pattern was nearly constant throughout

TABLE 5. Results (shown in seconds) of the Frame-by-Frame Analysis of the Motion-Picture Film Taken During the First Group's Three Runs

Exit Order	Vest No.	Exit time in seconds at right front	Vest No.	Exit time in seconds at left rear	Vest No.	Exit time in seconds at right rear
1st run						
1	40	2.46	6	3.92	4	1.42
2	12	3.58	**	5.96	26	6.00
3	22	5.04	*	7.08	36	7.29
4	20	5.50	*	12.71	37	7.33
5	24	6.83	*	14.33	33	8.54
6	30	6.83	*	16.21	*	9.63
7	16	8.00	*	19.83	*	10.75
8	13	9.63	*	22.00	*	12.63
9	28	10.29	3	23.25	*	16.54
10	17	11.63	19	26.54	*	18.29
11	9	13.33			*	19.29
12	11	14.08			34	25.88
13	35	17.08				
14	27	17.58				
15	31	21.83				
16	38	23.38				
17	2	25.17				
18	21	26.63				
2nd run						
1	40	1.79	6	2.54	4	1.33
2	12	2.71	8	4.67	26	4.43
3	20	3.75	14	6.63	37	5.38
4	22	4.00	15	10.88	39	5.79
5	24	4.33	32	14.17	10	6.67
6	30	5.17	23	15.46	**	7.54
7	28	7.50	29	16.75	33	8.50
8	16	8.00	25	18.55	*	9.63
9	13	8.54	3	19.38	1	11.64
10	9	10.33	*	22.04	18	13.00
11	17	10.83			7	15.83
12	11	12.04			21	22.21
13	27	13.67				
14	35	14.92				
15	31	17.08				
16	38	18.54				
17	2	20.83				
18	34	22.25				
3rd run						
1	40	2.13	6	2.17	4	1.25
2	12	2.83	8	4.54	26	4.04
3	22	3.56	14	5.00	37	5.04
4	20	4.00	*	9.64	36	5.63
5	24	4.79	5	11.54	39	6.67
6	30	4.88	32	14.25	10	8.96
7	9	6.33	23	15.21	33	9.79
8	28	6.83	29	17.21	7	11.96
9	16	7.75	25	19.34	18	13.42
10	13	9.00	3	21.08	1	16.50
11	11	10.33	**	22.50	21	18.04
12	17	11.33			34	22.58
13	35	13.67				
14	27	15.04				
15	31	17.96				
16	38	18.79				
17	2	20.33				

* Vest number uncertain
** Vest number not visible

that group's work; only two subjects changed from one exit to another during the second run (see Figure 4), and apparently another did during the third run (see Table 5). But in the second group's first run (without any recordings being played), a large majority of the subjects used the front exit. Exact numbers are not available except for the left rear door, but the recorded total times together with debriefing comments made by observers indicate that, without any speech indicating which exits were available, most subjects simply headed for the one exit that they had seen in the front of the cabin or followed their neighbors to it. The fewest used the left rear exit--only four went out that way. On the second run (during which six people changed from one exit to another, according to Figure 4), eight used the left rear exit. And during the third run for this group, three more moved out that way, bringing the total to 11--as many as used that doorway during the first group's runs.

Although people might have become aware of other exits by talking with each other between trials, little conversation was observed; further, no one commented on having learned of other exits during the reentering of the simulator. One obvious explanation for the change is the attraction of the voices calling people to "Exit here." Indeed, among the first group's subjects, only one volunteered that the sounds had some special value in leading him out. Among the second group, though, six subjects mentioned (on the questionnaire or in later, informal conversations) the sounds, so it seems reasonable to attribute to the speech recordings at least part of the behavior modification that took place when people moved from previously used exits to ones that were new to them.

Look at the evacuation times at the left rear exit as shown in Table 4.

These times are most important because they are the only ones for which some additional information (the number of subjects passing through the doorway) is available. In Table 4 (A) the recorded time decreases between the first and second runs and remains constant between the second and third; the number of people involved is nearly constant from run to run.(Table 5). In Table 4 (B), the recorded time changes in a different way, but this fact has to be considered in conjunction with the change in the number of subjects involved: in the first run, when only 4 people went out through the left rear exit, the time was quite short; in the second run, with 8 people, the time was the same as it had been for the first group with 10 people; and in the third run, when both groups had 11 people using the left rear exit, the times were matched. Despite the lack of corroborating evidence from the motion-picture film (because no film exists for the second group), we want to suggest that this family of values represents a different kind of learning in the two groups, and the variations in times at the other two exits are compatible with the suggestion. The concept is that the subjects who received the speech during their first run were able to make rational selections of which exit to use because the voices told them where exits were and they could judge from the sound which one was closest. In the second run, when the speech was missing, those people had already learned most of what they

needed to know about using the available doorways and so, when the third run started, they had little improvement to make. (A glance at Table 5 shows that the difference between the second and third runs is totally the result of the last subject's changing to a different exit.) Thus, when the sounds were played at the beginning of a listener's experience in this simulator, he or she rapidly figured out how to make the most valuable decisions about getting out safely. For the second group, that kind of improvement was not nearly so rapid. They received no speech to guide them out during their first run, and so, although they recognized the urgent need to move, they did not have enough help to permit them to do more than work their ways more or less aimlessly through the cabin. Some understanding of the task accrued to them during the first run, but not nearly as much was gained by group two as by group one. When the second run started and the sounds were turned on, the situation was only a little better for this group than it had been during the first run for group one. Improvement was noted, but it was certainly less (when weighted by the number of people using each exit) than the first group had made. The third runs for the two groups were apparently matched in every physical regard: the sounds were the same and the number of people using the various exits was probably the same. Yet the performance for the second group certainly continued to improve between the second and third runs; it remained essentially constant during that interval for the first group. These facts recommend the conclusion that the availability of speech eased the task and promoted safer and faster evacuation of the simulator. However, the conclusion cannot be accepted with complete confidence because of the procedural problems. In fact, even had motion picture records been available for every test, a number of types of control trials would still be lacking. Such studies as this probably require not two groups of 40 subjects, but 20 or 30 groups in order to allow the testing of each of the critical factors. If confirming replications are also to be done, of course the total number of trials would be multiplied accordingly.

V. Conclusions.

Studies of binaural hearing (6,7,8,10,11,12) suggested that speech sounds might be less resistant to masking than are nonspeech sounds. Experiments demonstrated that this assumption is not appropriate when the nonspeech sounds are given a message to convey, especially when that message can be more readily delivered by using words. Previous research (10) showed that when subjects are deprived of vision, their walking behavior can be changed by presenting them with binaurally localizable signals, and so tests were run using speech recordings at the exits of the CAMI emergency evacuation simulator. The voices called out, "Exit here," "This way," and "This way out," and people who had the opportunity to listen to them in an evacuation situation in which the illumination level was quite low and the subjects' vision was further obscured as if by smoke or dust performed better than people who did not hear the sounds.

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